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# RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Navy Department

## AERODYNAMIC CHARACTERISTICS OF THREE DEEP-STEPPED PLANING-TAIL FLYING-BOAT HULLS

By

John M. Riebe and Rodger L. Naeseth





NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
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# AERODYNAMIC CHARACTERISTICS OF THREE DEEP-STEPPED PLANING-TAIL FLYING-BOAT HULLS

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## SUMMARY

An investigation was made in the Langley 300 MPH 7- by 10-foot tunnel to determine the aerodynamic characteristics of three deep-stepped planing-tail flying-boat hulls differing only in the amount of step fairing. The hulls were derived by increasing the unfaired step depth of a planing-tail hull of a previous aerodynamic investigation to a depth about 92 percent of the hull beam. Tests were also made on a transverse-stepped hull with an extended afterbody for the purpose of comparison and in order to extend and verify the results of a previous investigation.

The investigation indicated that the extended afterbody hull had a minimum drag coefficient about the same as a conventional hull, 0.0066, and an angle-of-attack range for minimum drag of 3° to 5°. The hull with a deep unfaired step had a minimum drag coefficient of 0.0057 which was 14 percent less than the transverse stepped hull with extended afterbody; the hulls with step fairing had up to 44 percent less minimum drag coefficient than the transverse-stepped hull, or slightly more drag than a streamlined body having approximately the same length and volume.

Longitudinal and lateral instability varied little with step fairing and was about the same as a conventional hull.

## INTRODUCTION

In view of the requirements for increased range and speed in flying boats, the Bureau of Aeronautics, Navy Department, has requested an investigation of the aerodynamic characteristics of flying-boat hulls as affected by hull dimensions and hull shape.

The results of one phase of the investigation, presented in reference 1, have indicated that substantial drag reductions can be obtained on planing-tail flying-boat hulls if proper step fairings are incorporated on the hull. It was believed that further drag reductions might be obtained on this type of hull by deepening the step because of a reduction in skin area. In the present investigation exploratory tests were made to provide information in this respect.

Unpublished data from tests in Langley tank no. 2 have indicated that the three deep-stepped hulls of the present investigation would have satisfactory hydrodynamic characteristics.

To extend and verify the results of a previous investigation, tests were made of a transverse stepped hull, Langley tank model 203. Since this hull had aerodynamic characteristics about the same as a conventional hull, it is used as a basis of comparison in this report.

As in the previous aerodynamic investigation of planing-tail hulls (reference 1) all hull aerodynamic characteristics determined include the effect of interference of the support wing.

## COEFFICIENTS AND SYMBOLS

The results of the tests are presented as standard NACA coefficients of forces and moments. Rolling-, yawing-, and pitching-moment coefficients are given about the location (wing 30-percent chord point) shown in figure 1. Except where noted, the wing area, mean aerodynamic chord, and span used in determining the coefficients and Reynolds numbers are those of a hypothetical flying boat described in reference 2. The data are referred to the stability axes, which are a system of axes having their origin at the center of moments shown in figure 1 and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry. The positive directions of the stability axes are shown in figure 3.

The coefficients and symbols are defined as follows:

$C_L$ lift coefficient (Lift/qS)

$C_D$ drag coefficient (Drag/qS)

$C_Y$ lateral-force coefficient (Y/qS)

$C_l$ rolling-moment coefficient (L/qSb)

$C_m$ pitching-moment coefficient (M/qSc)

$C_n$ yawing-moment coefficient (N/qSb)

Lift = -Z

Drag = -X when $\psi = 0$

X, Y, Z force along axes, pounds

L, M, N moments about axes, foot-pounds

q free-stream dynamic pressure, pounds per square foot $\left(\frac{\rho V^2}{2}\right)$

S wing area of a $\frac{1}{10}$-scale model of a hypothetical flying boat (18.264 sq ft)

$\bar{c}$ wing mean aerodynamic chord (M.A.C.) of a $\frac{1}{10}$-scale model of a hypothetical flying boat (1.377 ft)

b wing span of a $\frac{1}{10}$-scale model of a hypothetical flying boat (13.971 ft)

V air velocity, feet per second

$\rho$ mass density of air, slugs per cubic foot

$\alpha$ angle of attack of hull base line, degrees

$\psi$ angle of yaw, degrees

R Reynolds number, based on wing mean aerodynamic chord of a $\frac{1}{10}$-scale model of a hypothetical flying boat

$C_{m_\alpha}$ rate of change of pitching-moment coefficient with angle of attack $\left(\frac{\partial C_m}{\partial \alpha}\right)$

$C_{n_\psi}$ rate of change of yawing-moment coefficient with angle of yaw $\left(\frac{\partial C_n}{\partial \psi}\right)$

$C_{Y_\psi}$ rate of change of lateral-force coefficient with angle of yaw $\left(\frac{\partial C_Y}{\partial \psi}\right)$

## MODEL AND APPARATUS

The deep-stepped hull lines were drawn by the Langley Hydrodynamics Division by increasing the step of hull 221B of reference 1 from a depth which was 23 percent of the hull beam to a depth 92 percent of the hull beam while maintaining the same height at the sternpost. Langley tank model 203 with extended afterbody was the same configuration reported in reference 3. Dimensions of the hulls are given in figures 1 and 2 and tables I to IV; photographs of the deep-step fairings are given in figure 4. The test model was the same one used in the investigation of reference 1; transformation from one hull to another was facilitated by cutting the underportion of the model and replacing interchangeable blocks corresponding to each step fairing condition. The hull and interchangeable blocks were constructed of laminated mahogany and were finished with pigmented varnish.

The volumes, surface areas, maximum cross-sectional areas, and side areas, for the hulls are compared in the following table:

| Hull | Volume ($in.^3$) | Surface area ($in.^2$) | Maximum cross-sectional area ($in.^2$) | Side area ($in.^2$) |
|---|---|---|---|---|
| 203 extended | 13,338 | 4857 | 182 | 1845 |
| 221E | 10,354 | 4164 | 182 | 1512 |
| 221G | 10,904 | 4217 | 182 | 1568 |
| 221F | 11,502 | 4314 | 182 | 1636 |

The hull was attached to a wing which was mounted horizontally in the tunnel as shown in figure 5. The wing was also the same one used in the investigation of reference 1 and was not a scale model of the hypothetical wing. It was set at an incidence of $4^\circ$ on the model, had a 20-inch chord, and was of the NACA 4321 section.

## TESTS

### Test Conditions

The tests were made in the Langley 300 MPH 7- by 10-foot tunnel at dynamic pressures of approximately 25, 100, and 170 pounds per square foot corresponding to airspeeds of 100, 201, and 274 miles per hour. Reynolds numbers for these airspeeds, based on the mean aerodynamic chord of the hypothetical flying boat, were approximately $1.30 \times 10^6$, $2.50 \times 10^6$, and $3.10 \times 10^6$, respectively. Corresponding Mach numbers were 0.13, 0.26, and 0.348.

### Corrections

Blocking corrections have been applied to the wing and wing-plus-hull data. The hull drag has been corrected for horizontal buoyancy effects caused by a tunnel static-pressure gradient. Angles of attack have been corrected for structural deflections caused by aerodynamic forces.

### Test Procedure

The aerodynamic characteristics of the hulls with interference of the mounting wing were determined by testing the wing alone and the wing-and-hull combinations under identical conditions. The hull aerodynamic coefficients were thus determined by subtraction of wing-alone coefficients from wing and hull coefficients.

Tests were made at three Reynolds numbers. Because of structural limitations of the mounting wing, it was necessary to limit the data at the higher Reynolds numbers to the angle-of-attack range shown.

To minimize possible errors resulting from transition shift on the wing, the wing transition was fixed at the leading edge by means of roughness strips of carborundum particles of approximately 0.008-inch diameter. The particles were applied for a length of 8-percent airfoil chord measured along the airfoil contour from the leading edge on both upper and lower surfaces.

Hull transition for all tests were fixed by a strip of 0.008-inch diameter carborundum particles $\frac{1}{2}$-inch wide and located approximately 5 percent of the hull length aft of the bow. All tests were made with the mounting setup shown in figure 5.

## RESULTS AND DISCUSSION

The aerodynamic characteristics of the deep-stepped planing-tail hulls in pitch are presented in figure 6; aerodynamic characteristics in yaw are given in figure 7. The aerodynamic characteristics of Langley tank model 203 with extended afterbody in pitch and yaw are presented in figures 8 and 9, respectively.

Langley tank model 203 with extended afterbody had a minimum drag coefficient of 0.0066, as in reference 3, which is about the same as a conventional hull of the same over-all length-beam ratio, reference 2; the angle-of-attack range for minimum drag extended from 3° to 5°.

The hull with the unfaired deep step, model 221E, had a minimum drag coefficient of 0.0057 which was 14 percent less than the hull with extended afterbody or a conventional hull. Comparison of the drag results of model 221E with that of model 221B of reference 1, indicates that increasing the step from a depth 23 percent of the hull beam to 92 percent of the hull beam resulted in a drag coefficient reduction of 12 percent. The hull with the fairing whose elements approached straight lines, 221F, had a minimum drag coefficient of 0.0037 which was slightly larger than the drag coefficient of a streamlined body having approximately the same length and volume. The importance of proper step-fairing design in reducing aerodynamic drag on deep-stepped planing-tail hulls is shown by the larger value of drag coefficient, 0.0045, for the hull with the concave step fairing, model 221G. The drag coefficient for this hull configuration was about 32 percent less than the hull with extended afterbody, whereas the hull with the fuller fairing, 221F, was about 44 percent less.

Tuft studies of the step portion of the hulls (fig. 10) indicate that the lower drag for the hulls with step fairing results from the elimination of separation which occurs on the sides of the unfaired deep-stepped hull.

Minimum drag coefficients based on $(\text{volume})^{2/3}$ ($C_{D_{V_{min}}}$) and frontal area ($C_{D_{A_{min}}}$) and skin area ($C_{D_{W_{min}}}$) are presented in table V along with drag coefficients based on hypothetical wing area. These data indicate that model 221F had the least drag for a unit volume and for unit surface area.

As with the planing-tail hulls of a previous investigation (reference 1) the angle-of-attack range for minimum drag occurred from about 3° to 5°.

Longitudinal and lateral instability as shown by the parameters $\partial C_m/\partial \alpha$ and $\partial C_n/\partial \psi$, table V, varied little with step fairing and was about the same as a conventional hull or a hull with extended afterbody.

In order to compare the results of these tests with investigations made of other hulls and fuselages, the parameters $K_f$, $\partial C_{n_f}'/\partial \psi'$, and $\partial C_n/\partial \beta_1$ as given in references 4, 5, and 6, respectively, are also included in table V. The parameter $K_f$ is a fuselage moment factor, in the form of $\partial C_m/\partial \alpha'$ based on hull beam and length where $\alpha'$ is in radians. The yawing-moment coefficient, $C_{n_f'}$, in $\partial C_{n_f}'/\partial \psi$ is based on volume and is given about a reference axis 0.3 of hull length from the nose. The parameter $\partial C_n/\partial \beta$ is based on hull side area and length where the yawing moment is also given about a reference axis 0.3 of hull length from the nose and $\beta$ is given in radians. Instability as given by the parameter $\partial C_n/\partial \beta$ agreed closely with values given in references 5 and 6.

## CONCLUSIONS

The results of tests in the Langley 300 MPH 7- by 10-foot tunnel to determine the aerodynamic characteristics of three deep-stepped planing-tail flying boat hulls, differing only in the amount of step fairing, indicated the following conclusions.

1. The planing-tail hull with a deep unfaired step, 221E, had a minimum drag coefficient of 0.0057, about 14 percent less than a conventional hull; the hulls with step fairing had up to 44 percent less minimum drag coefficient than a conventional hull or slightly more drag than a streamlined body having approximately the same length and volume.

2. The angle-of-attack range for minimum drag was generally in the 3° to 5° range for all planing-tail hulls tested.

3. Longitudinal and lateral instability was the same for all planing-tail hulls and was about the same as a conventional hull.

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TABLE I

OFFSETS FOR LANGLEY TANK MODEL 221E

[All dimensions are in inches]

| Station | Distance to F.P. | Keel above $B_L$ | Cove above $B_L$ | Upper chine above $B_L$ | Lower chine above $B_L$ | Lower chine half beam | Radius and half maximum beam | Height of hull at $C_L$ | Line of centers above $B_L$ | Angle of chine flare (deg) | Bottom of hull | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | $\frac{1}{2}$ in. Butt | 1 in. Butt | $1\frac{1}{2}$ in. Butt | 2 in. Butt | $2\frac{1}{2}$ in. Butt | 3 in. Butt | $3\frac{1}{2}$ in. Butt | 4 in. Butt | $4\frac{1}{2}$ in. Butt |
| F.P. | 0 | 10.30 | | | 10.30 | 0 | 0 | 11.00 | 11.00 | | | | | | | | | | |
| $\frac{1}{2}$ | 2.15 | 5.49 | | | 8.30 | 2.30 | 2.30 | 14.29 | 11.98 | 10 | 6.48 | 7.49 | 8.14 | 8.32 | | | | | |
| 1 | 4.25 | 3.76 | | | 6.71 | 3.06 | 3.06 | 15.72 | 12.66 | ↓ | 4.52 | 5.30 | 6.09 | 6.56 | 6.77 | 6.72 | | | |
| 2 | 8.50 | 1.83 | | | 4.59 | 3.86 | 3.86 | 17.36 | 13.50 | | 2.40 | 2.96 | 3.53 | 4.01 | 4.38 | 4.60 | 4.64 | | |
| 3 | 12.75 | .80 | | | 3.24 | 4.32 | 4.32 | 18.41 | 14.08 | | 1.21 | 1.64 | 2.06 | 3.49 | 2.85 | 3.10 | 3.25 | 3.28 | |
| 4 | 17.00 | .27 | | | 2.36 | 4.61 | 4.61 | 19.12 | 14.52 | | .59 | .92 | 1.25 | 1.98 | 1.89 | 2.14 | 2.33 | 2.42 | 2.38 |
| 5 | 21.25 | .04 | | | 1.81 | 4.79 | 4.79 | 19.60 | 14.81 | ↓ | .29 | .55 | .80 | 1.04 | 1.30 | 1.52 | 1.70 | 1.82 | 1.85 |
| 6 | 25.50 | 0 | | | 1.51 | 4.89 | 4.89 | 19.88 | 14.99 | 5 | .19 | .40 | .59 | .78 | .98 | 1.18 | 1.33 | 1.46 | 1.52 |
| 7 | 29.75 | 0 | | | 1.40 | 4.92 | 4.92 | 19.99 | 15.07 | 0 | .18 | .36 | .55 | .73 | .92 | 1.09 | 1.23 | 1.33 | 1.40 |
| 8 | 34.00 | 0 | 10.29 | 10.29 | 1.40 | 4.925 | 4.925 | 20.00 | 15.08 | 0 | .18 | .36 | .55 | .73 | .92 | 1.09 | 1.23 | 1.33 | 1.40 |
| 9 | 38.25 | 0 | 10.32 | 10.47 | 1.39 | 4.50 | ↓ | ↓ | ↓ | | | .36 | | .73 | | 1.09 | | 1.33 | |
| 10 | 42.50 | 0 | 10.01 | 10.66 | 1.12 | 3.14 | | | | | | .36 | | .73 | | 1.09 | | | |
| 11 | 46.75 | 0 | 9.33 | 10.85 | .26 | .73 | | | | | | | | | | | | | |
| $11\frac{1}{4}$ F | 47.90 | 0 | 9.08 | 10.87 | 0 | 0 | | | | | | | | | | | | | |
| $11\frac{1}{4}$ A | 47.90 | 9.08 | 9.08 | 10.87 | | | | | | | | | | | | | | | |
| 12 | 51.00 | 9.25 | | 11.01 | | | ↓ | | ↓ | | | | | | | | | | |
| 13 | 55.25 | 9.40 | | 11.19 | | | 4.91 | | 15.09 | | | | | | | | | | |
| 14 | 59.50 | 9.59 | | 11.36 | | | 4.86 | | 15.14 | | | | | | | | | | |
| 15 | 63.75 | 9.78 | | 11.51 | | | 4.75 | | 15.25 | | | | | | | | | | |
| 16 | 68.00 | 9.97 | | 11.65 | | | 4.61 | | 15.39 | | | | | | | | | | |
| 17 | 72.25 | 10.16 | | 11.77 | | | 4.43 | | 15.57 | | | | | | | | | | |
| 18 | 76.50 | 10.34 | | 11.86 | | | 4.17 | | 15.83 | | | | | | | | | | |
| 19 | 80.75 | 10.53 | | 11.94 | | | 3.87 | | 16.13 | | | | | | | | | | |
| 20 | 85.00 | 10.72 | | 11.99 | | | 3.50 | | 16.50 | | | | | | | | | | |
| 21 | 89.25 | 10.91 | | 12.03 | | | 3.08 | | 16.92 | | | | | | | | | | |
| 22 | 93.50 | 11.09 | | 12.04 | | | 2.61 | | 17.39 | | | | | | | | | | |
| 23 | 97.75 | 11.28 | | 12.06 | | | 2.15 | | 17.85 | | | | | | | | | | |
| 24 | 102.00 | 11.47 | | 12.08 | | | 1.69 | | 18.31 | | | | | | | | | | |
| 25 | 106.25 | 11.66 | | 12.10 | | | 1.22 | | 18.78 | | | | | | | | | | |
| 26 | 110.50 | 11.85 | | 12.12 | | | .76 | | 19.24 | | | | | | | | | | |
| 27 | 114.75 | 12.02 | | 12.12 | | | .31 | | 19.69 | | | | | | | | | | |
| A.P. | 116.65 | 12.12 | | 12.12 | | | .10 | ↓ | 19.96 | | | | | | | | | | |

TABLE II

OFFSETS OF LANGLEY TANK MODEL 221G

[All dimensions are in inches]

| Station | Distance to F.P. | Keel above $B_L$ | Cove above $B_L$ | Upper chine above $B_L$ | Lower chine above $B_L$ | Lower chine half beam | Radius and half maximum beam | Height of hull at $\mathcal{C}_L$ | Line of centers above $B_L$ | Angle of chine flare (deg) | Bottom of hull - Heights and half breadths | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | 1 in. Butt | 2 in. Butt | 3 in. Butt | 4 in. Butt | 1 in. W.L. | 2 in. W.L. | 3 in. W.L. | 4 in. W.L. | 5 in. W.L. | 6 in. W.L | 7 in. W.L. | 8 in. W.L. | 9 in. W.L. | 10 in. W.L. | 11 in. W.L. |
| F.P. | 0 | 10.30 | | | 10.30 | 0 | 0 | 11.00 | 11.00 | | | | | | | | | | | | | | | | |
| $\frac{1}{2}$ | 2.13 | 5.49 | | | 8.30 | 2.30 | 2.30 | 14.29 | 11.98 | 10 | 7.49 | 8.32 | | | | | | | | | | | | | |
| 1 | 4.25 | 3.76 | | | 6.71 | 3.06 | 3.06 | 15.72 | 12.66 | 10 | 5.30 | 6.56 | 6.72 | | | | | | | | | | | | |
| 2 | 8.50 | 1.83 | | | 4.59 | 3.86 | 3.86 | 17.36 | 13.50 | 10 | 2.96 | 4.01 | 4.60 | | | | | | | | | | | | |
| 3 | 12.75 | .80 | | | 3.24 | 4.32 | 4.32 | 18.41 | 14.08 | 10 | 1.64 | 2.49 | 3.10 | 3.28 | | | | | | | | | | | |
| 4 | 17.00 | .27 | | | 2.36 | 4.61 | 4.61 | 19.12 | 14.52 | 10 | .92 | 1.58 | 2.14 | 2.42 | | | | | | | | | | | |
| 5 | 21.25 | .04 | | | 1.81 | 4.79 | 4.79 | 19.60 | 14.81 | 10 | .55 | 1.04 | 1.52 | 1.82 | | | | | | | | | | | |
| 6 | 25.50 | 0 | | | 1.51 | 4.89 | 4.89 | 19.88 | 14.99 | 5 | .40 | .78 | 1.18 | 1.46 | | | | | | | | | | | |
| 7 | 29.75 | 0 | | | 1.40 | 4.92 | 4.92 | 19.99 | 15.07 | 0 | .36 | .73 | 1.09 | 1.33 | | | | | | | | | | | |
| 8 | 34.00 | 0 | 1.50 | | 1.40 | 4.925 | 4.925 | 20.00 | 15.08 | 0 | .36 | .73 | 1.09 | 1.33 | | | | | | | | | | | |
| 9 | 38.25 | 0 | 1.49 | | 1.39 | 4.50 | ↓ | ↓ | ↓ | | .36 | .73 | 1.09 | 1.33 | | 4.55 | 4.62 | 4.70 | 4.76 | 4.82 | 4.89 | | | | |
| 10 | 42.50 | 0 | 1.22 | | 1.12 | 3.14 | | | | | .36 | .73 | 1.09 | 4.69 | | 3.35 | 3.60 | 3.83 | 4.08 | 4.31 | 4.55 | 4.75 | 4.88 | | |
| 11 | 46.75 | 0 | .36 | | .26 | .73 | | | | | 1.07 | 3.34 | 5.55 | 7.80 | .95 | 1.40 | 1.85 | 2.30 | 2.75 | 3.20 | 3.65 | 4.10 | 4.50 | 4.82 | |
| $11\frac{1}{4}$ F | 47.90 | 0 | 0 | | 0 | 0 | | | | | 2.43 | 4.40 | 6.35 | 8.31 | .34 | .79 | 1.28 | 1.79 | 2.30 | 2.82 | 3.33 | 3.89 | 4.33 | 4.73 | |
| $11\frac{1}{4}$ A | 47.90 | 0 | | | | | | | | | 2.43 | 4.40 | 6.35 | 8.31 | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | |
| 12 | 51.00 | 3.63 | | | | | ↓ | | ↓ | | 5.15 | 6.55 | 7.96 | 9.36 | | | | .24 | .91 | 1.60 | 2.32 | 3.05 | 3.74 | 4.42 | |
| 13 | 55.25 | 6.40 | | | | | 4.91 | | 15.09 | | 7.36 | 8.35 | 9.31 | 10.23 | | | | | | | .62 | 1.65 | 2.68 | 3.75 | 4.75 |
| 14 | 59.50 | 8.07 | | | | | 4.86 | | 15.14 | | 8.79 | 9.42 | 10.07 | 10.74 | | | | | | | | | 1.40 | 2.88 | 4.40 |
| 15 | 63.75 | 9.10 | | | | | 4.75 | | 15.25 | | 9.59 | 10.10 | 10.62 | 11.11 | | | | | | | | | | 1.82 | 3.83 |
| 16 | 68.00 | 9.73 | | | | | 4.61 | | 15.39 | | 10.13 | 10.55 | 10.97 | 11.38 | | | | | | | | | | .72 | 3.10 |
| 17 | 72.25 | 10.08 | | | | | 4.43 | | 15.57 | | 10.48 | 10.85 | 11.24 | 11.61 | | | | | | | | | | | 2.45 |
| 18 | 26.50 | 10.34 | | 11.86 | | | 4.17 | | 15.83 | | 10.69 | 11.07 | 11.45 | 11.83 | | | | | | | | | | | 1.88 |
| 19 | 80.75 | 10.53 | | 11.94 | | | 3.87 | | 16.13 | | 10.90 | 11.26 | 11.63 | | | | | | | | | | | | 1.36 |
| 20 | 85.00 | 10.72 | | 11.99 | | | 3.50 | | 16.50 | | 11.08 | 11.45 | 11.81 | | | | | | | | | | | | .82 |
| 21 | 89.25 | 10.91 | | 12.03 | | | 3.08 | | 16.92 | | 11.27 | 11.65 | 12.02 | | | | | | | | | | | | .25 |
| 22 | 93.50 | 11.09 | | 12.04 | | | 2.61 | | 17.39 | | | | | | | | | | | | | | | | |
| 23 | 97.75 | 11.28 | | 12.06 | | | 2.15 | | 17.85 | | | | | | | | | | | | | | | | |
| 24 | 102.00 | 11.47 | | 12.08 | | | 1.69 | | 18.31 | | | | | | | | | | | | | | | | |
| 25 | 106.25 | 11.66 | | 12.10 | | | 1.22 | | 18.78 | | | | | | | | | | | | | | | | |
| 26 | 110.50 | 11.85 | | 12.12 | | | .76 | | 19.24 | | | | | | | | | | | | | | | | |
| 27 | 114.75 | 12.02 | | 12.12 | | | .31 | | 19.69 | | | | | | | | | | | | | | | | |
| A.P. | 110.65 | 12.12 | | 12.12 | | | .10 | ↓ | 19.90 | | | | | | | | | | | | | | | | |

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TABLE III

OFFSETS FOR LANGLEY TANK MODEL 221F

[All dimensions are in inches]

| Station | Distance to F.P. | Keel above $B_L$ | Cove above $B_L$ | Upper chine above $B_L$ | Lower chine above $B_L$ | Lower chine half beam | Radius and half maximum beam | Height of hull at $\mathcal{L}$ | Line of centers above $B_L$ | Angle of chine flare (deg) | Bottom of hull - heights and half breadths | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | 1 in. Butt | 2 in. Butt | 3 in. Butt | 4 in. Butt | 1 in. W.L. | 2 in. W.L. | 3 in. W.L. | 4 in. W.L. | 5 in. W.L. | 6 in. W.L. | 7 in. W.L. | 8 in. W.L | 9 in. W.L | 10 in. W.L. | 11 in. W.L. |
| F.P. | 0 | 10.30 | | | 10.30 | 0 | 0 | 11.00 | 11.00 | | | | | | | | | | | | | | | | |
| ½ | 2.13 | 5.49 | | | 8.30 | 2.30 | 2.30 | 14.29 | 11.98 | 10 | 7.49 | 8.32 | | | | | | | | | | | | | |
| 1 | 4.25 | 3.76 | | | 6.71 | 3.06 | 3.06 | 15.72 | 12.66 | | 5.30 | 6.56 | 6.72 | | | | | | | | | | | | |
| 2 | 8.50 | 1.83 | | | 4.59 | 3.86 | 3.86 | 17.36 | 13.50 | | 2.96 | 4.01 | 4.60 | | | | | | | | | | | | |
| 3 | 12.75 | .80 | | | 3.24 | 4.32 | 4.32 | 18.41 | 14.08 | | 1.64 | 2.49 | 3.10 | 3.28 | | | | | | | | | | | |
| 4 | 17.00 | .27 | | | 2.36 | 4.61 | 4.61 | 19.12 | 14.52 | | .92 | 1.58 | 2.14 | 2.42 | | | | | | | | | | | |
| 5 | 21.25 | .04 | | | 1.81 | 4.79 | 4.79 | 19.60 | 14.81 | ↓ | .55 | 1.04 | 1.52 | 1.82 | | | | | | | | | | | |
| 6 | 25.50 | 0 | | | 1.51 | 4.89 | 4.89 | 19.88 | 14.99 | 5 | .40 | .78 | 1.18 | 1.46 | | | | | | | | | | | |
| 7 | 29.75 | | | | 1.40 | 4.92 | 4.92 | 19.99 | 15.07 | 0 | .36 | .73 | 1.09 | 1.33 | | | | | | | | | | | |
| 8 | 34.00 | | 1.50 | | 1.40 | 4.925 | 4.925 | 20.00 | 15.08 | 0 | .36 | .73 | 1.09 | 1.33 | | | | | | | | | | | |
| 9 | 38.25 | | 1.49 | | 1.39 | 4.50 | | | | | .36 | .73 | 1.09 | 1.33 | | 4.59 | 4.74 | 4.87 | | | | | | | |
| 10 | 42.50 | | 1.22 | | 1.12 | 3.14 | | | | | .36 | .73 | 1.09 | 2.70 | | 3.61 | 4.11 | 4.46 | 4.75 | 4.89 | | | | | |
| 11 | 46.75 | ↓ | .36 | | .26 | .73 | | | | | .66 | 1.80 | 3.03 | 4.62 | 1.32 | 2.17 | 2.99 | 3.64 | 4.17 | 4.56 | 4.80 | 4.90 | | | |
| 11¼ F | 47.90 | 0 | .10 | | 0 | 0 | | | | | 1.16 | 2.29 | 3.52 | 5.10 | .86 | 1.75 | 2.60 | 3.33 | 3.95 | 4.41 | 4.72 | 4.86 | | | |
| 11¼ A | 47.90 | .10 | | | | | | | | | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | | | |
| 12 | 51.00 | 1.42 | | | | | ↓ | | ↓ | | 2.45 | 3.54 | 4.75 | 6.27 | | .57 | 1.51 | 2.40 | 3.17 | 3.85 | 4.35 | 4.67 | 4.86 | | |
| 13 | 55.25 | 3.15 | | | | | 4.91 | | 15.09 | | 4.14 | 5.20 | 6.32 | 7.75 | | | | .85 | 1.82 | 2.74 | 3.50 | 4.13 | 4.56 | 4.85 | 4.90 |
| 14 | 59.50 | 4.77 | | | | | 4.86 | | 15.14 | | 5.67 | 6.65 | 7.67 | 8.95 | | | | | .25 | 1.32 | 2.34 | 3.27 | 4.02 | 4.57 | 4.85 |
| 15 | 63.75 | 6.26 | | | | | 4.75 | | 15.25 | | 7.07 | 7.91 | 8.84 | 9.93 | | | | | | | .87 | 2.11 | 3.15 | 4.05 | 4.68 |
| 16 | 68.00 | 7.58 | | | | | 4.61 | | 15.39 | | 8.29 | 9.05 | 9.84 | 10.71 | | | | | | | | .60 | 1.95 | 3.18 | 4.27 |
| 17 | 72.25 | 8.71 | | | | | 4.43 | | 15.57 | | 9.33 | 9.97 | 10.62 | 11.29 | | | | | | | | | .47 | 2.05 | 3.57 |
| 18 | 76.50 | 9.62 | | 11.86 | | | 4.17 | | 15.83 | | 10.12 | 10.66 | 11.17 | 11.71 | | | | | | | | | | .74 | 2.70 |
| 19 | 80.75 | 10.29 | | 11.94 | | | 3.87 | | 16.13 | | 10.70 | 11.13 | 11.54 | | | | | | | | | | | | 1.74 |
| 20 | 85.00 | 10.71 | | 11.99 | | | 3.50 | | 16.50 | | 11.08 | 11.45 | 11.81 | | | | | | | | | | | | .76 |
| 21 | 89.25 | 10.91 | | 12.03 | | | 3.08 | | 16.92 | | | | | | | | | | | | | | | | |
| 22 | 93.50 | 11.09 | | 12.04 | | | 2.61 | | 17.39 | | | | | | | | | | | | | | | | |
| 23 | 97.75 | 11.28 | | 12.06 | | | 2.15 | | 17.85 | | | | | | | | | | | | | | | | |
| 24 | 102.00 | 11.47 | | 12.08 | | | 1.69 | | 18.31 | | | | | | | | | | | | | | | | |
| 25 | 106.25 | 11.66 | | 12.10 | | | 1.22 | | 18.78 | | | | | | | | | | | | | | | | |
| 26 | 110.50 | 11.85 | | 12.12 | | | .76 | | 19.24 | | | | | | | | | | | | | | | | |
| 27 | 114.75 | 12.02 | | 12.12 | | | .31 | | 19.69 | | | | | | | | | | | | | | | | |
| A.P | 116.65 | 12.12 | | 12.12 | | | .10 | ↓ | 19.90 | | | | | | | | | | | | | | | | |

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TABLE IV

OFFSETS FOR NACA HULL MODEL 203 WITH EXTENDED AFTERBODY

[All dimensions are in inches]

| Station | Distance to F.P. | Keel above $B_L$ | Chine above $B_L$ | Radius and half beam at chine | Height of hull at $C_L$ | Line of centers above $B_L$ | Angle of chine flare (deg) | Forebody bottom, heights above $B_L$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Butt ½ in. | Butt 1 in. | Butt 1½ in. | Butt 2 in. | Butt 2½ in. | Butt 3 in. | Butt 3½ in. | Butt 4 in. | Butt 4½ in. |
| F.P. | 0 | 10.30 | 10.30 | 0 | 11.00 | 11.00 | | | | | | | | | | |
| ½ | 2.13 | 5.49 | 8.30 | 2.30 | 14.29 | 11.98 | 10 | 6.48 | 7.49 | 8.14 | 8.32 | | | | | |
| 1 | 4.25 | 3.76 | 6.71 | 3.06 | 15.72 | 12.66 | 10 | 4.52 | 5.30 | 6.09 | 6.56 | 6.77 | 6.72 | | | |
| 2 | 8.50 | 1.83 | 4.59 | 3.86 | 17.36 | 13.50 | 10 | 2.40 | 2.96 | 3.53 | 4.01 | 4.38 | 4.60 | 4.64 | | |
| 3 | 12.75 | .80 | 3.24 | 4.32 | 18.41 | 14.09 | 10 | 1.21 | 1.64 | 2.06 | 2.49 | 2.85 | 3.10 | 3.25 | 3.28 | |
| 4 | 17.00 | .27 | 2.36 | 4.61 | 19.12 | 14.52 | 10 | .59 | .92 | 1.25 | 1.58 | 1.89 | 2.14 | 2.33 | 2.42 | 2.38 |
| 5 | 21.25 | .04 | 1.81 | 4.79 | 19.60 | 14.81 | 10 | .29 | .55 | .80 | 1.04 | 1.30 | 1.52 | 1.70 | 1.82 | 1.85 |
| 6 | 25.50 | 0 | 1.51 | 4.89 | 19.88 | 14.99 | 5 | .19 | .40 | .59 | .78 | .98 | 1.18 | 1.33 | 1.46 | 1.52 |
| 7 | 29.75 | 0 | 1.40 | 4.92 | 19.99 | 15.07 | 0 | .18 | .36 | .55 | .73 | .92 | 1.09 | 1.23 | 1.33 | 1.40 |
| 8 | 34.00 | 0 | 1.40 | 4.925 | 20.00 | 15.08 | 0 | .18 | .36 | .55 | .73 | .92 | 1.09 | 1.23 | 1.33 | 1.40 |
| 9 | 38.25 | 0 | 1.40 | 4.925 | 20.00 | 15.08 | 0 | .18 | .36 | .55 | .73 | .92 | 1.09 | 1.23 | 1.33 | 1.40 |
| 10 | 42.50 | 0 | 1.40 | 4.925 | 20.00 | 15.08 | 0 | .18 | .36 | .55 | .73 | .92 | 1.09 | 1.23 | 1.33 | 1.40 |
| 11 | 46.75 | 0 | 1.40 | 4.925 | 20.00 | 15.08 | 0 | .18 | .36 | .55 | .73 | .92 | 1.09 | 1.23 | 1.33 | 1.40 |
| 12 F | 51.04 | 0 | 1.40 | 4.925 | 20.00 | 15.08 | 0 | .18 | .36 | .55 | .73 | .92 | 1.09 | 1.23 | 1.33 | 1.40 |
| 12 A | 51.04 | 1.16 | 2.95 | 4.925 | 20.00 | 15.08 | | | | | | | | | | |
| 13 | 55.25 | 1.78 | 3.57 | 4.91 | 20.00 | 15.09 | | | | | | | | | | |
| 14 | 59.50 | 2.41 | 4.18 | 4.86 | 20.00 | 15.14 | | | | | | | | | | |
| 15 | 63.75 | 3.04 | 4.77 | 4.75 | 20.00 | 15.25 | | | | | | | | | | |
| 16 | 68.00 | 3.66 | 5.34 | 4.61 | 20.00 | 15.39 | | | | | | | | | | |
| 17 | 72.25 | 4.29 | 5.90 | 4.43 | 20.00 | 15.57 | | | | | | | | | | |
| 18 | 76.50 | 4.92 | 6.44 | 4.17 | 20.00 | 15.83 | | | | | | | | | | |
| 19 | 80.75 | 5.55 | 6.96 | 3.87 | 20.00 | 16.13 | | | | | | | | | | |
| 20 | 85.00 | 6.17 | 7.44 | 3.50 | 20.00 | 16.50 | | | | | | | | | | |
| 21 | 89.25 | 6.80 | 7.92 | 3.08 | 20.00 | 16.92 | | | | | | | | | | |
| 22 | 93.50 | 7.43 | 8.38 | 2.61 | 20.00 | 17.39 | | | | | | | | | | |
| 23 | 97.75 | 8.06 | 8.84 | 2.15 | 20.00 | 17.85 | | | | | | | | | | |
| 24 | 102.00 | 8.69 | 9.31 | 1.69 | 20.00 | 18.31 | | | | | | | | | | |
| 25 | 106.25 | 9.31 | 9.75 | 1.22 | 20.00 | 18.78 | | | | | | | | | | |
| 26 | 110.50 | 9.94 | 10.22 | .76 | 20.00 | 19.24 | | | | | | | | | | |
| 27 | 114.75 | 10.57 | 10.68 | .31 | 20.00 | 19.69 | | | | | | | | | | |
| A.P. | 116.65 | 10.85 | 10.89 | .10 | 20.00 | 19.90 | | | | | | | | | | |

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TABLE V

DRAG COEFFICIENTS AND STABILITY PARAMETERS FOR LANGLEY TANK MODELS 221E, 221G, 221F, AND 203 WITH EXTENDED AFTERBODY

[The drag coefficients are given for a Reynolds number of about $2.50 \times 10^6$]

| Model | $C_{D_{min}}$ | $(C_{D_V})_{min}$ | $(C_{D_A})_{min}$ | $(C_{D_W})_{min}$ | $\frac{\partial C_m}{\partial \alpha}$ | $K_f$ | $\left(\frac{\partial C_n}{\partial \psi}\right)_{\alpha=2^\circ}$ | $\left(\frac{\partial C_{n_f}'}{\partial \psi'}\right)_{\alpha=2^\circ}$ | $\left(\frac{\partial C_n}{\partial \beta}\right)_{\alpha=2^\circ}$ | $\left(\frac{\partial C_y}{\partial \psi}\right)_{\alpha=2^\circ}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 203 extended | 0.0066 | 0.031 | 0.095 | 0.0036 | 0.0050 | 1.10 | 0.0011 | 0.027 | -0.098 | 0.0050 |
| 221E | .0057 | .032 | .082 | .0036 | .0050 | 1.10 | .0010 | .029 | -.098 | .0048 |
| 221G | .0045 | .024 | .065 | .0028 | .0050 | 1.10 | .0010 | .026 | -.090 | .0050 |
| 221F | .0037 | .019 | .053 | .0023 | .0050 | 1.10 | .0010 | .026 | -.090 | .0050 |

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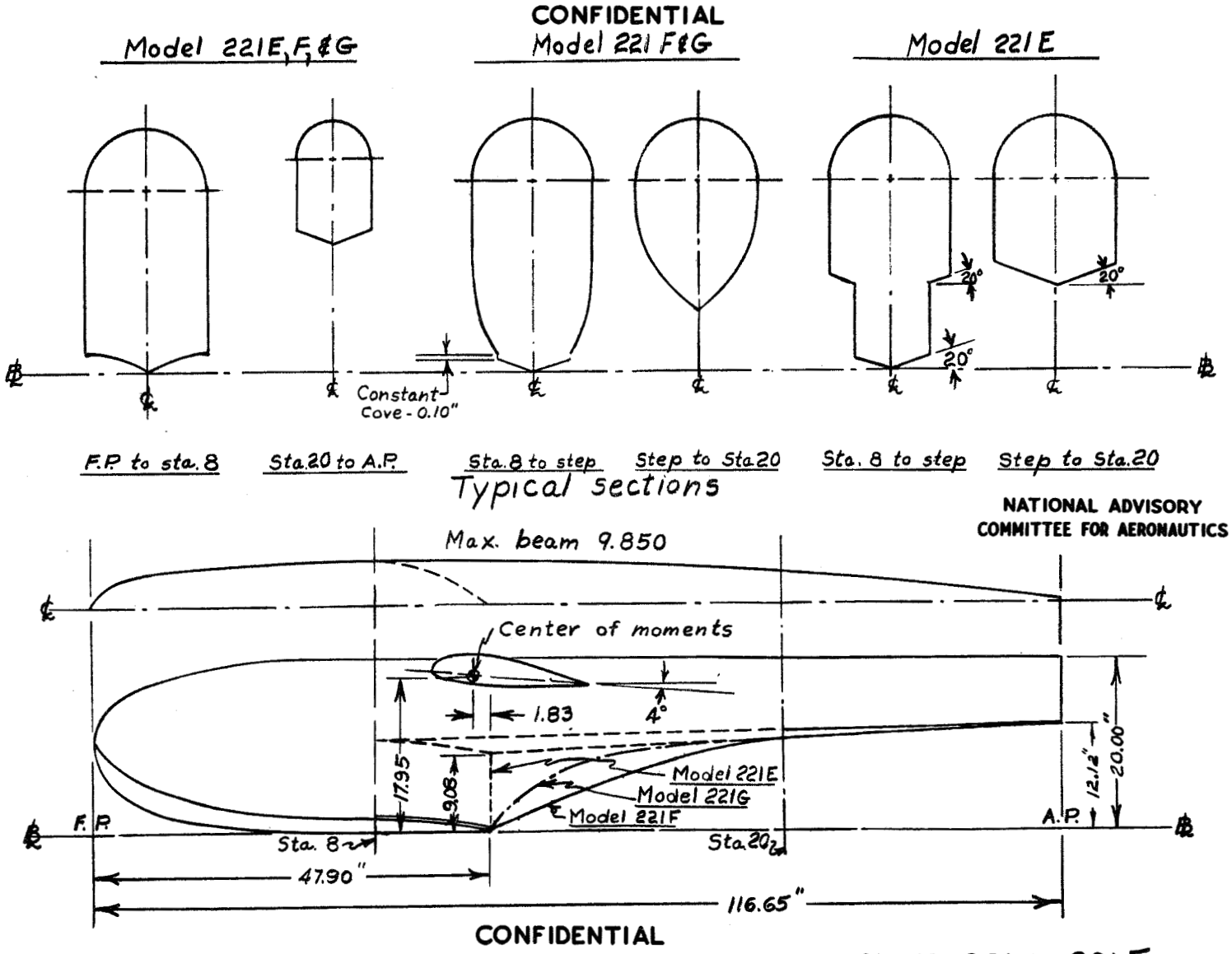


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Figure 1.- Lines of Langley tank models 221E, 221G, 221F.

Fig. 1

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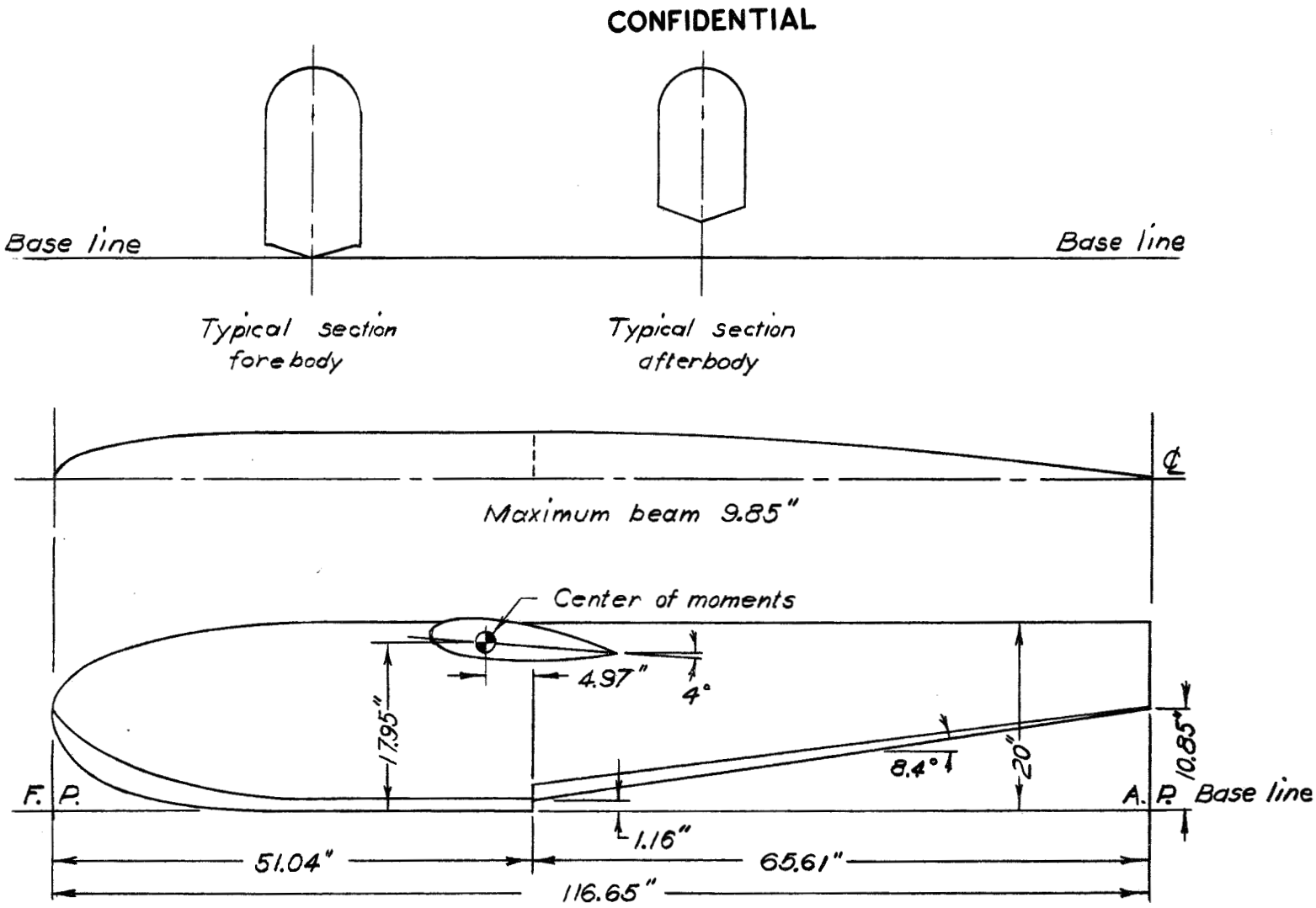


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Figure 2.- Lines of Langley tank model 203 with extended afterbody.

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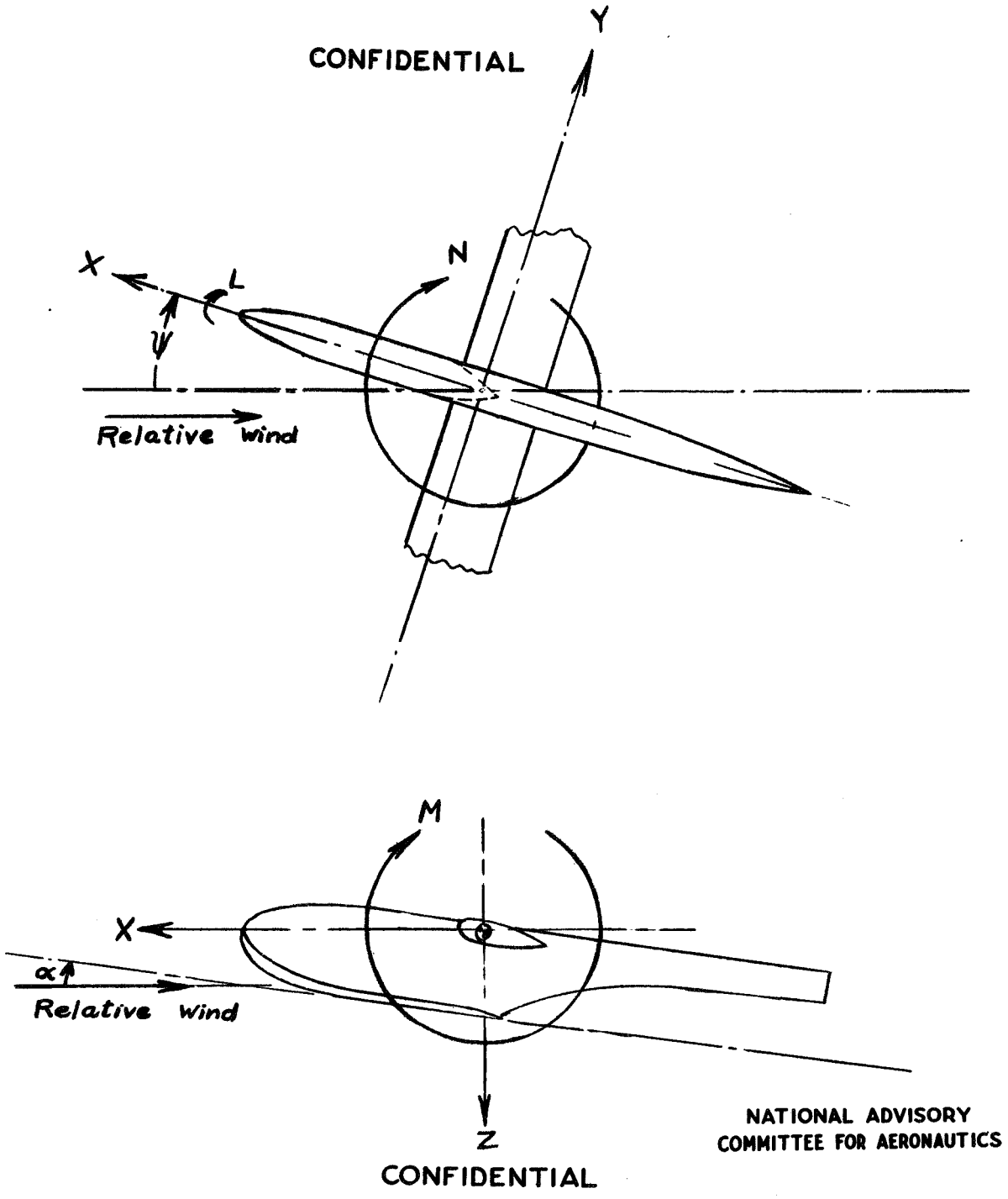


Figure 3.— System of stability axes. Positive values of forces, moments, and angles are indicated by arrows.

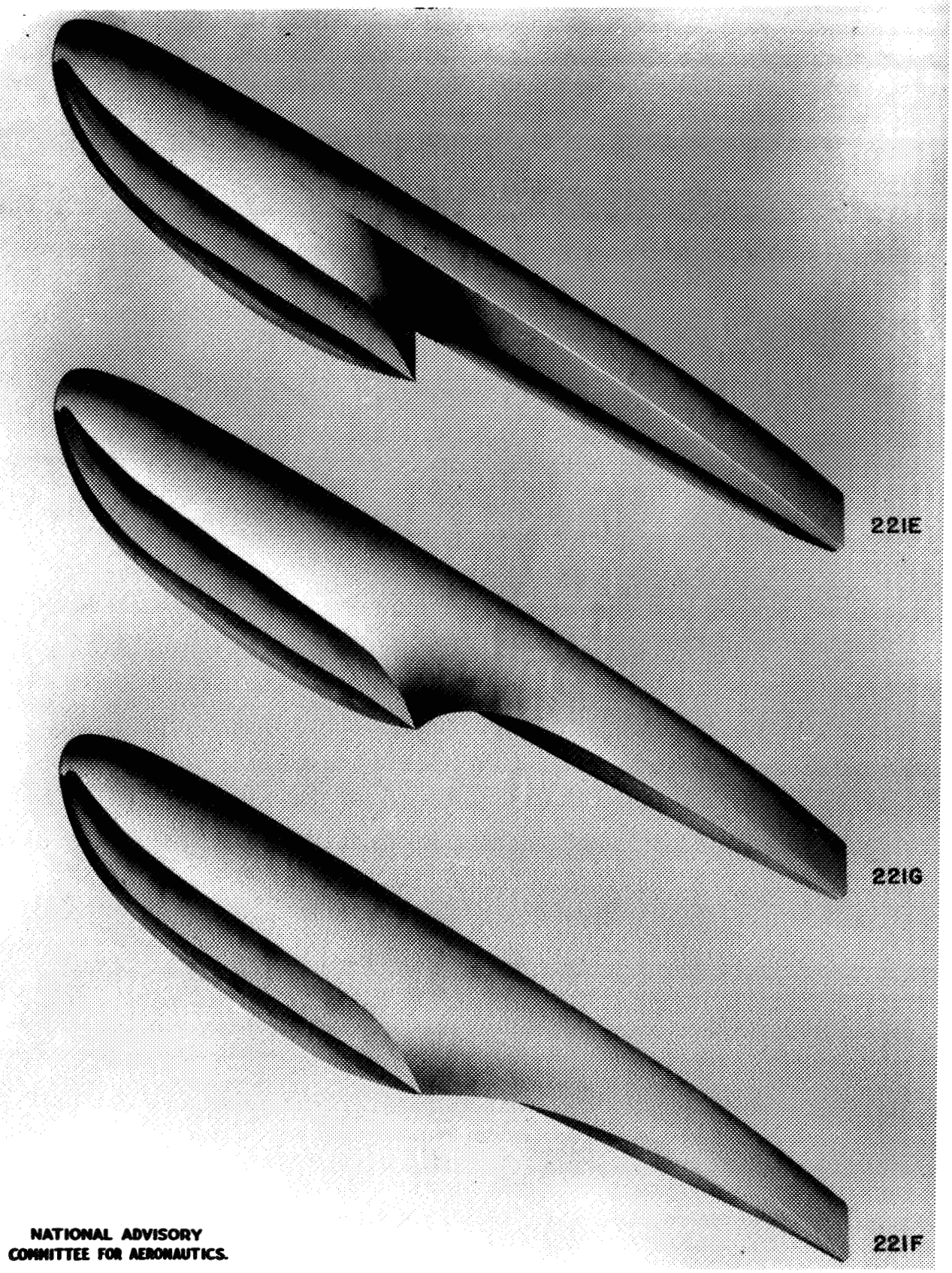


Figure 4.- Langley tank models 221E, 221G, and 221F tested in the Langley 300 MPH 7- by 10-foot tunnel.

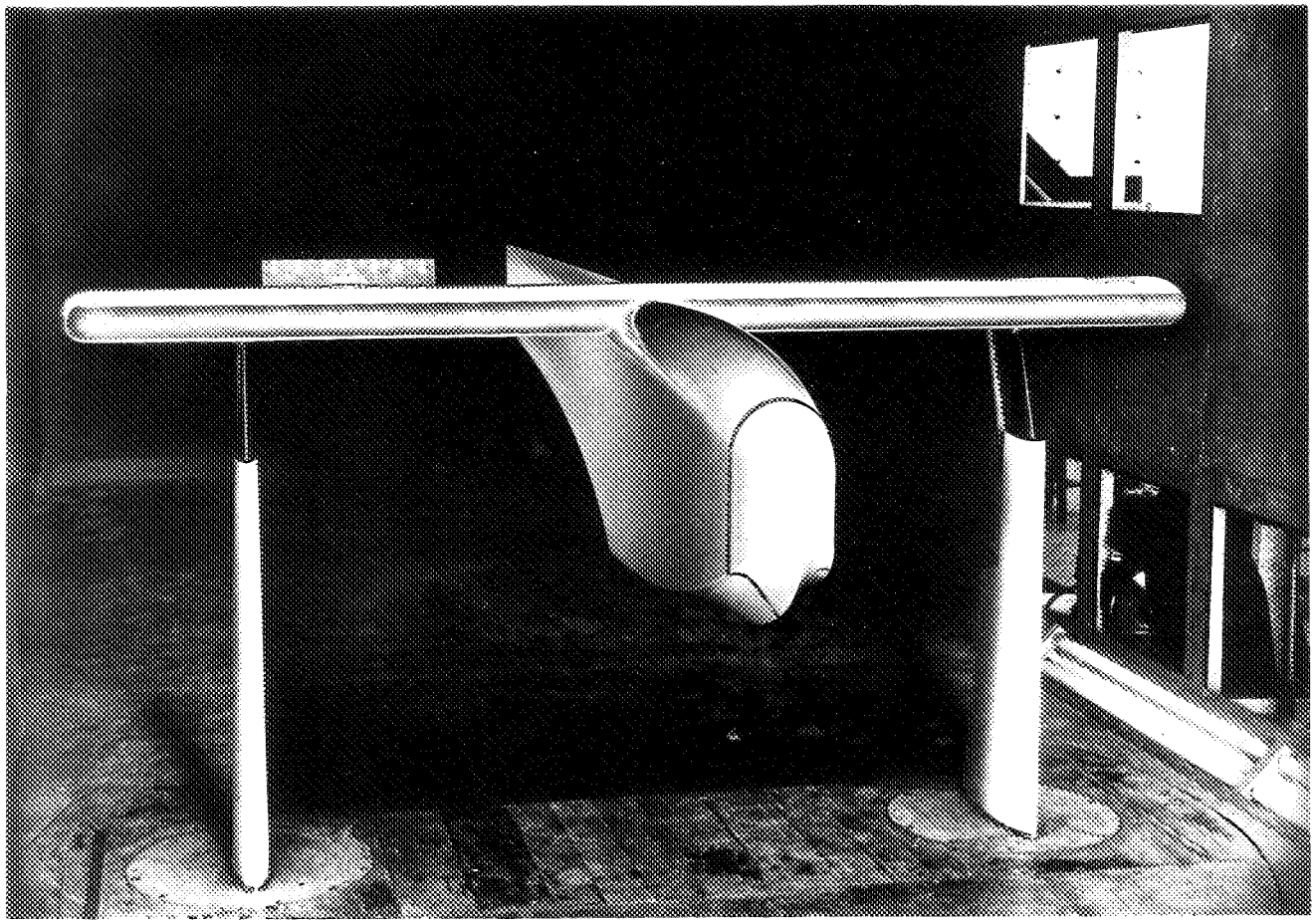

Figure 5.- Langley tank model 221F mounted in the Langley 300 MPH 7- by 10-foot tunnel.





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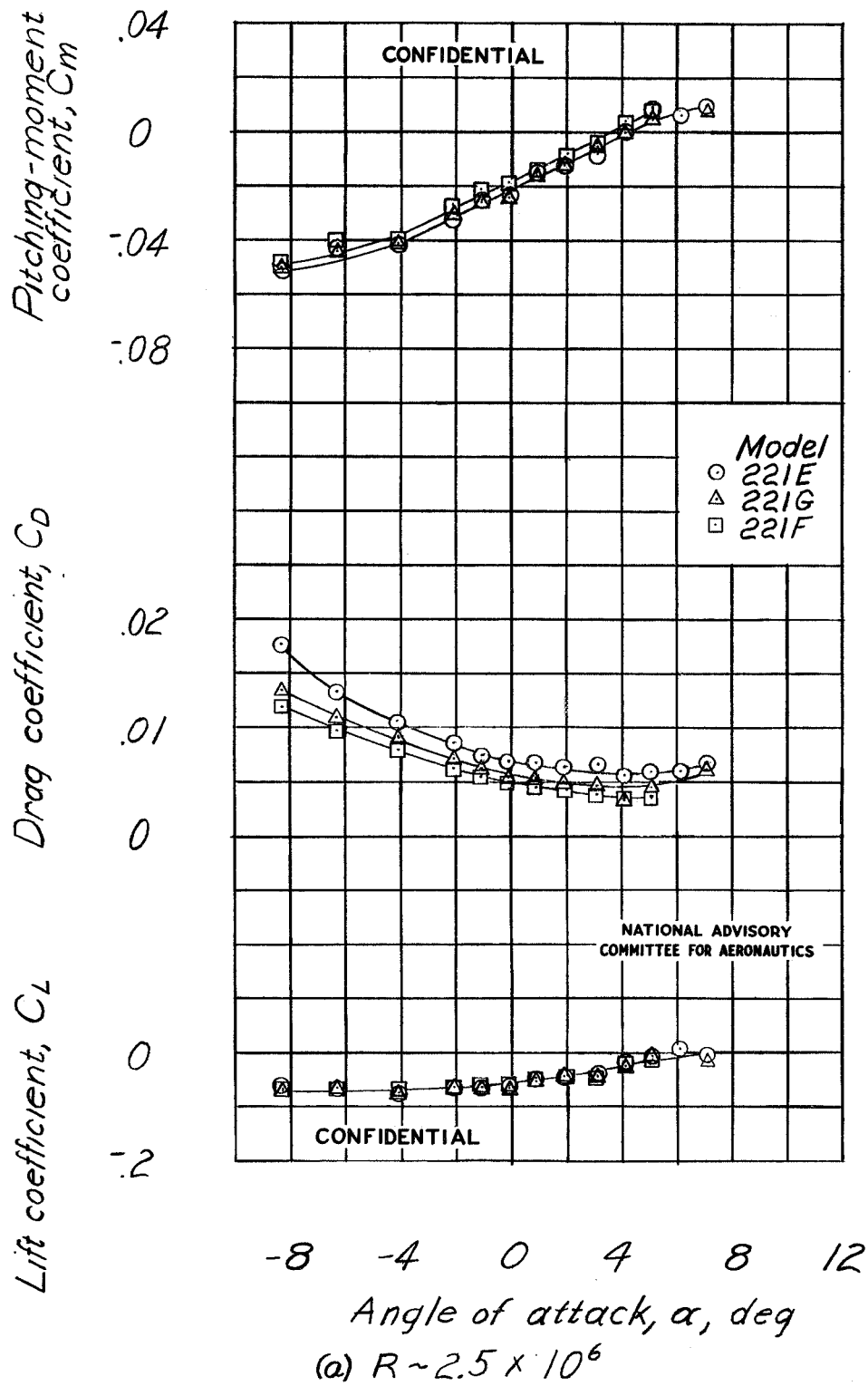
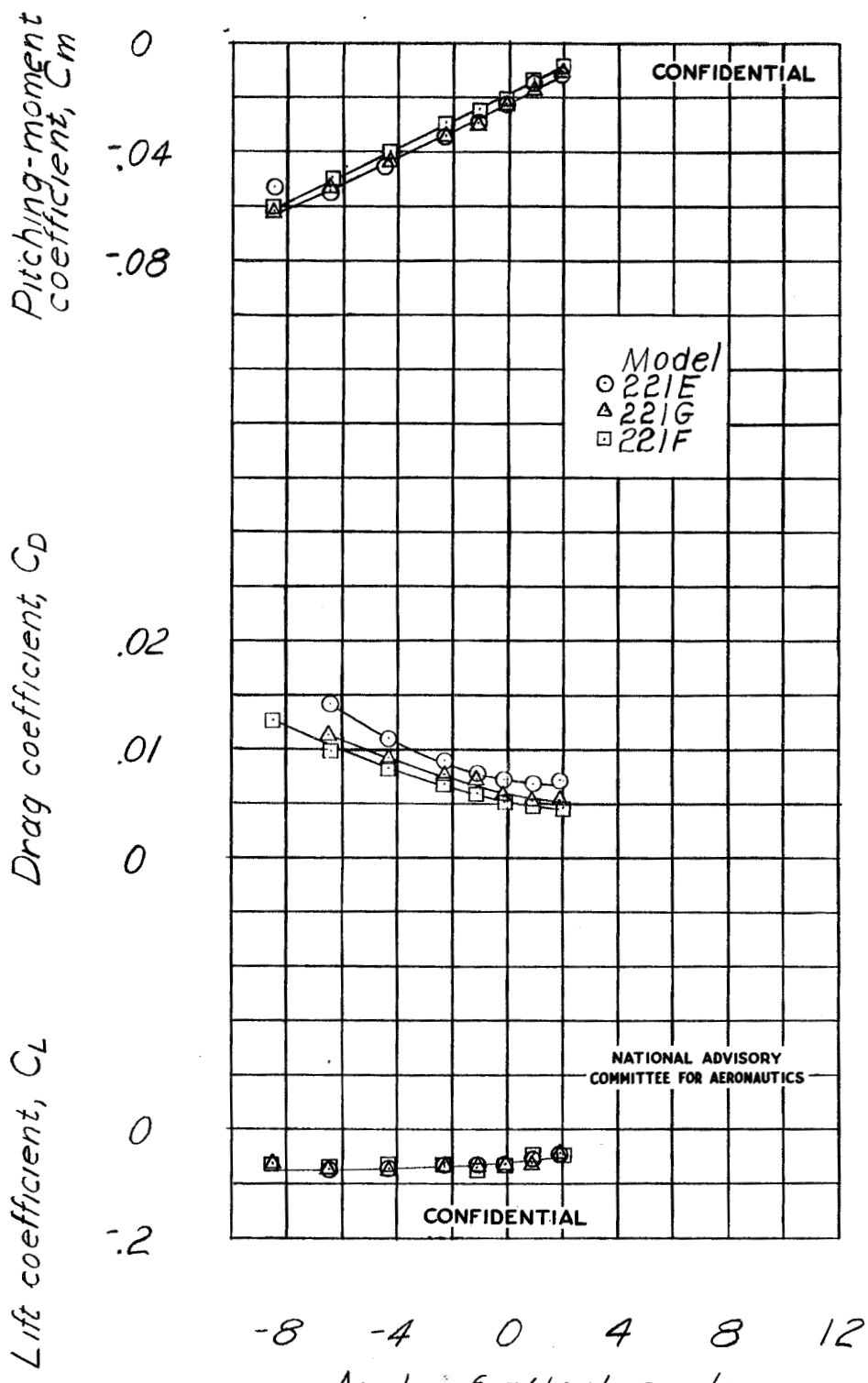



(a) $R \sim 2.5 \times 10^6$

Figure 6.- Aerodynamic characteristics in pitch of Langley tank models 221E, 221G, and 221F.




(b) $R \sim 3.1 \times 10^6$

Figure 6 .- Concluded.

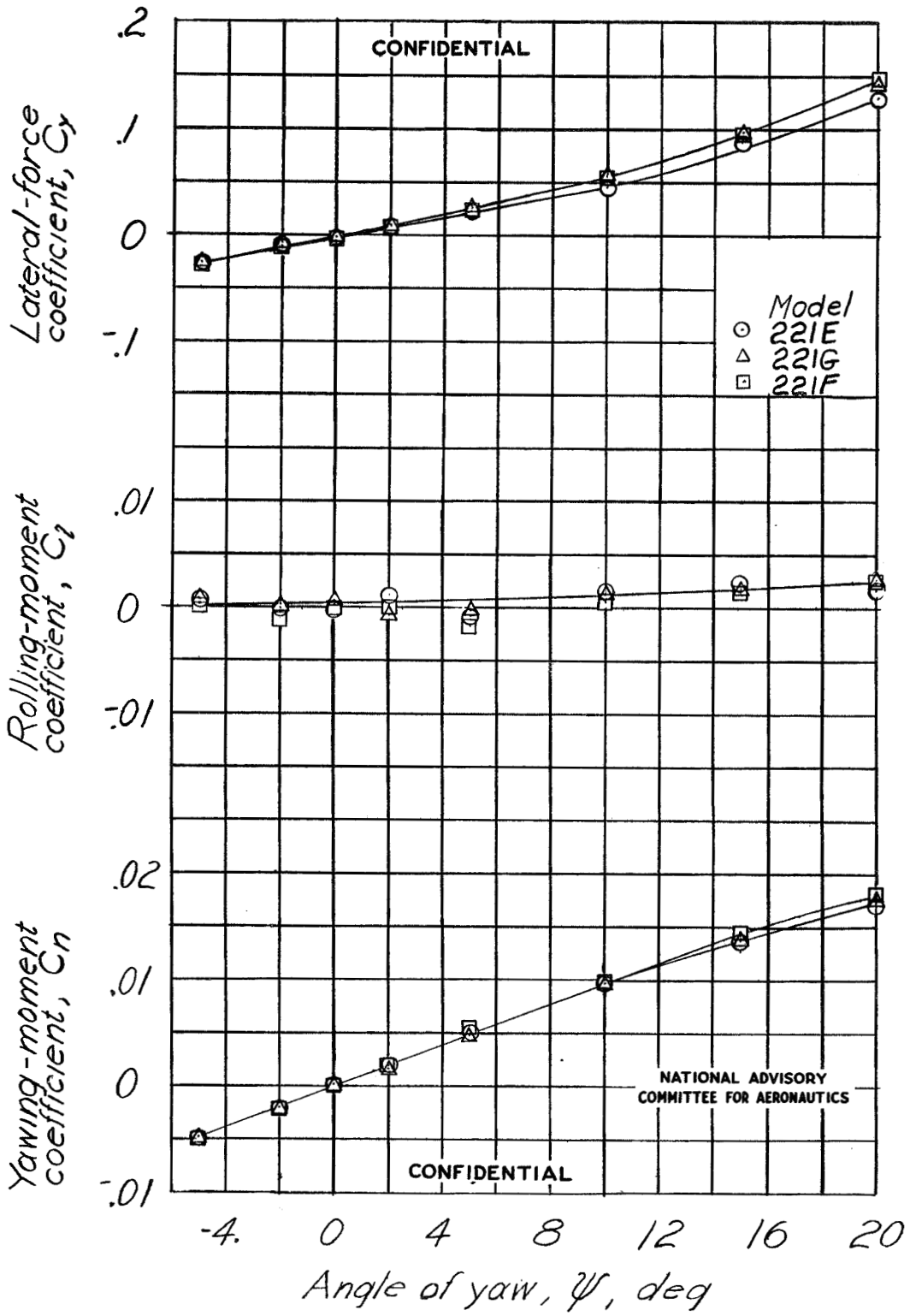



Figure 7.- Aerodynamic characteristics in yaw of Langley tank models 221E, 221G, and 221F, $\alpha = 2°$, $R \sim 1.3 \times 10^6$.

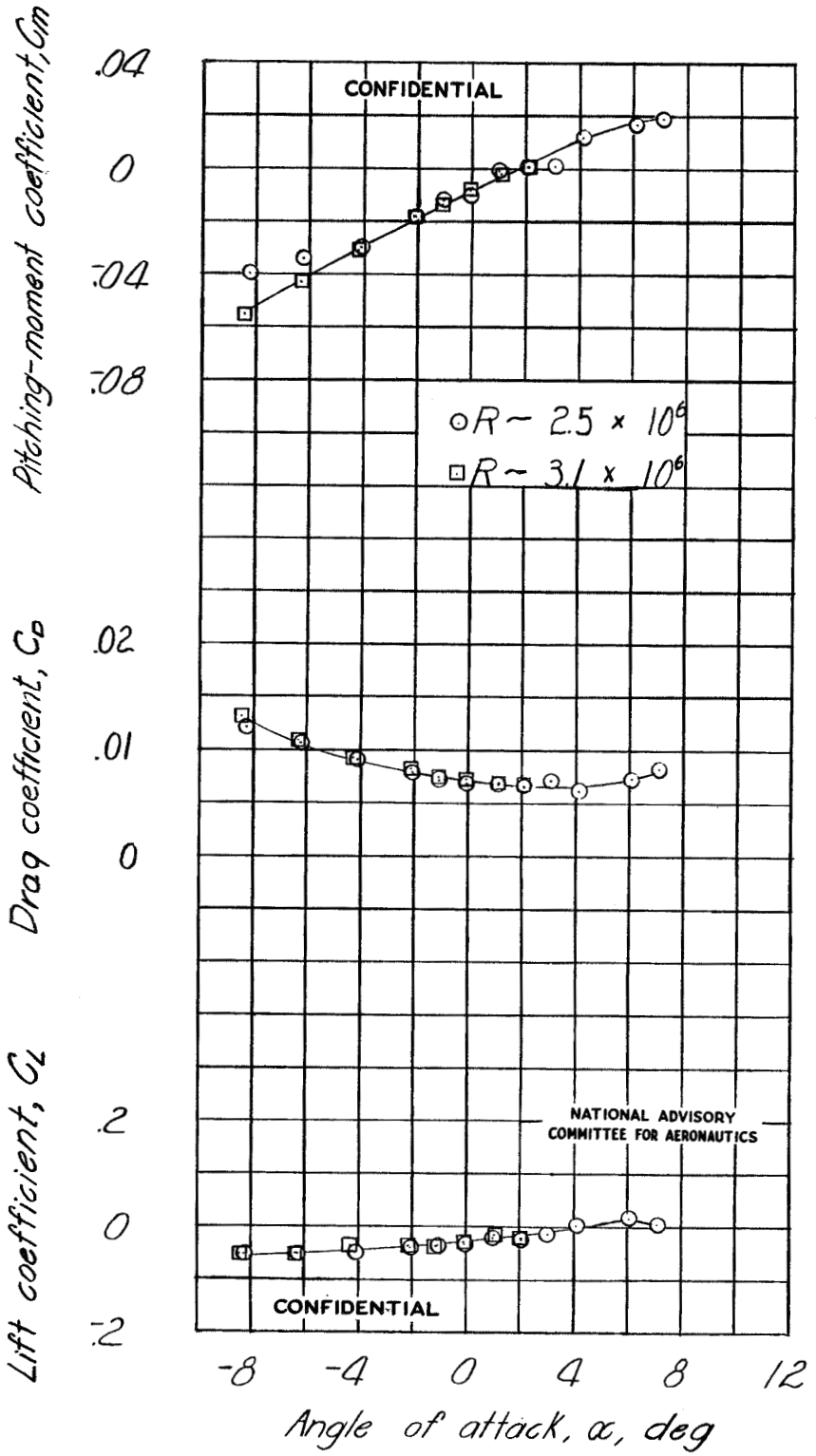



Figure 8.-Aerodynamic characteristics in pitch of Langley tank model 203 with extended afterbody.

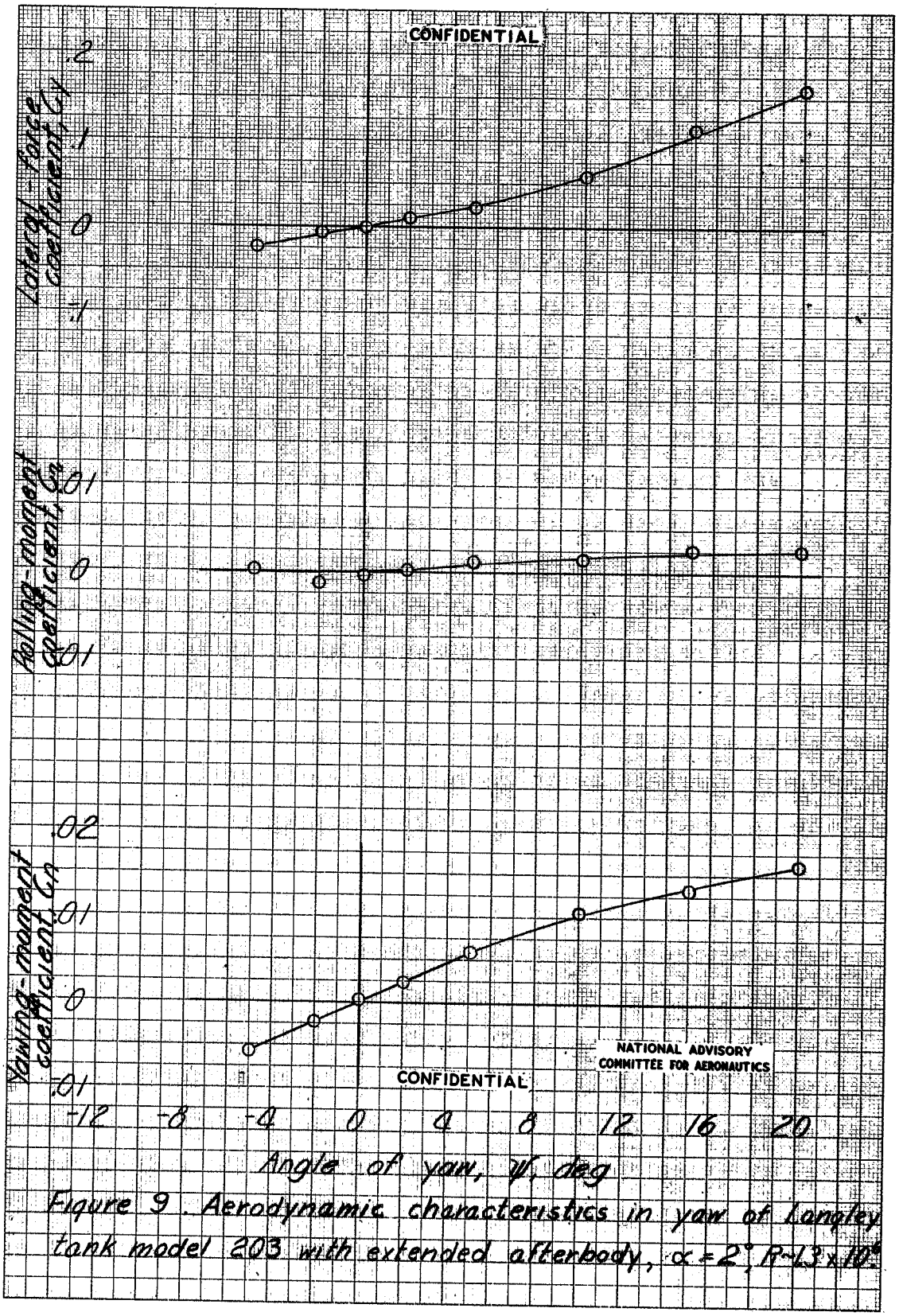
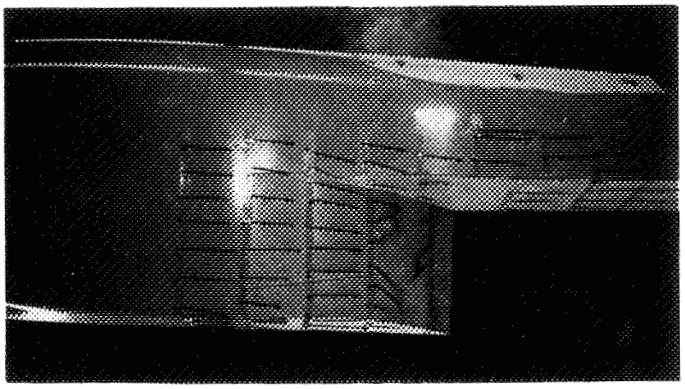
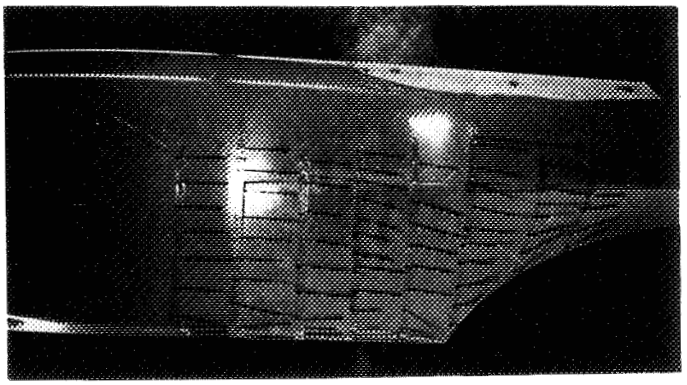


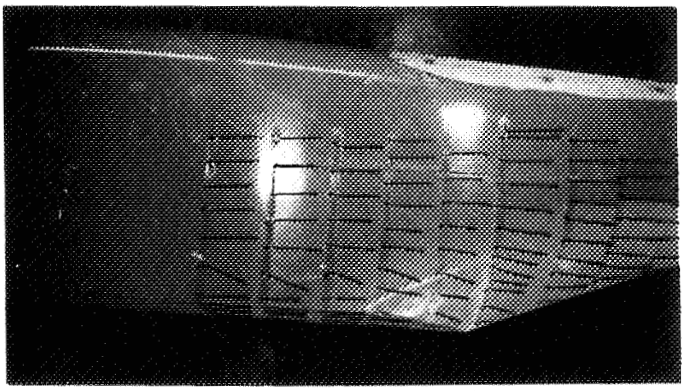

Figure 9. Aerodynamic characteristics in yaw of Langley tank model 203 with extended afterbody, $\alpha = 2°$, $R = 1.3 \times 10^6$



(a) Langley tank model 221E, $\alpha = 2^{\circ}$.



(b) Langley tank model 221G, $\alpha = 2^{\circ}$.



(c) Langley tank model 221F, $\alpha = 4^{\circ}$.

Figure 10.- Tuft studies of Langley tank models 221E, 221G, and 221F. Tests were made with models mounted on single strut support.

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